

2005

Decision aided compensation of residual frequency offset for MIMO-OFDM systems with nonlinear channel

Shouyi Yang
Zhengzhou University

Jiangtao Xi
University of Wollongong, jiangtao@uow.edu.au

Fang Wang
Mie University

Xiaomin Mu
xiaomin@uow.edu.au

Hideo Kobayashi
Mie University

Follow this and additional works at: <https://ro.uow.edu.au/infopapers>



Part of the [Physical Sciences and Mathematics Commons](#)

Recommended Citation

Yang, Shouyi; Xi, Jiangtao; Wang, Fang; Mu, Xiaomin; and Kobayashi, Hideo: Decision aided compensation of residual frequency offset for MIMO-OFDM systems with nonlinear channel 2005.
<https://ro.uow.edu.au/infopapers/2869>

Decision aided compensation of residual frequency offset for MIMO-OFDM systems with nonlinear channel

Abstract

In this paper, we propose a new approach to compensate the residual frequency offset (RFO) in multi-input multi-output orthogonal frequency division multiplexing (MIMO-OFDM) system with nonlinear channel working in the burst mode. The proposed approach consists of two stages. Firstly a decision aided method is proposed to eliminate the nonlinearity introduced by high power transmit amplifier (HPA). Then a new decision aided approach is employed to achieve the RFO compensation on the nonlinearity-free symbols. The effectiveness of the proposed approach has been verified by computer simulations.

Disciplines

Physical Sciences and Mathematics

Publication Details

Yang, S., Xi, J., Wang, F., Mu, X. & Kobayashi, H. (2005). Decision aided compensation of residual frequency offset for MIMO-OFDM systems with nonlinear channel. In K. Ngan & W. Siu (Eds.), *Proceedings of 2005 International Symposium on Intelligent Signal Processing and Communication Systems ISPACS 2005* (pp. 113-116). Hong Kong: IEEE.

DECISION AIDED COMPENSATION OF RESIDUAL FREQUENCY OFFSET FOR MIMO-OFDM SYSTEMS WITH NONLINEAR CHANNEL

Shouyi Yang[†], Jiangtao Xi^{††}, Fang Wang^{†††}, Xiaomin Mu[†] and Hideo Kobayashi^{†††}

[†] Faculty of Information Engineering, Zhengzhou University, China

^{††} School of Electrical, Computer and Telecommunications Engineering, the University of Wollongong, Australia

^{†††} Faculty of Engineering, Mie University, Japan

ABSTRACT

In this paper, we propose a new approach to compensate the residual frequency offset (RFO) in multi-input multi-output orthogonal frequency division multiplexing (MIMO-OFDM) system with nonlinear channel working in the burst mode. The proposed approach consists of two stages. Firstly a decision aided method is proposed to eliminate the nonlinearity introduced by high power transmit amplifier (HPA). Then a new decision aided approach is employed to achieve the RFO compensation on the nonlinearity-free symbols. The effectiveness of the proposed approach has been verified by computer simulations.

1. INTRODUCTION

Multi-input multi-output orthogonal frequency division multiplexing is a promising technology to increase the capacity of wireless communications over frequency selective fading channels. By using space-time coding, MIMO-OFDM can achieve transmit diversity and power gain over spatially un-coded systems without sacrificing the bandwidth [1]. However, when the MIMO-OFDM is operated in the burst mode, even very small residual frequency offset (RFO) with the estimation of carrier frequency offset (CFO) would cause significant degradation of the bit error rate (BER) performance, especially at the latter part of data symbols in a burst frame. Some compensation techniques have been proposed to remedy the problem and a recently proposed one is the so called decision-directed compensation algorithm which uses the decision (output) of the MIMO-OFDM system to estimate and compensate the RFO [2]. It is shown that the approach works well for the cases when the transmitter has a linear characteristic. However, in practice nonlinearity exists due to the use of the high power transmit amplifier (HPA), and in this case the RFO compensation in [2] will not be effective when the HPA working in the strongly nonlinear region [3].

In this paper we propose a new scheme to achieve nonlinear elimination and RFO compensation. With the scheme, a decision aided algorithm is firstly employed to cancel the nonlinearity in the received symbols and then a decision-based RFO compensation is applied to the nonlinear-free output of the first stage. The rest of the paper is organized as follows. Section 2 gives a brief description of the problem and the approach proposed in [2]. Then Section 3 presents the new method for both nonlinear elimination and RFO compensation. Numerical results are presented in Section 4. Finally, Section 5 concludes the paper.

2. PROBLEM STATEMENT

Figure 1 shows the block diagram of MIMO-OFDM transmitter with HPA. Let us assume that an M -ary modulation scheme is used. The Alamouti space-time block coding STBC encoder takes a block of two modulated symbols \mathbf{x}_1 and \mathbf{x}_2 in each encoding operation according to a code matrix given by

$$X = \begin{bmatrix} \mathbf{x}_1 & -\mathbf{x}_2^* \\ \mathbf{x}_2 & \mathbf{x}_1^* \end{bmatrix} \quad (1)$$

where $\mathbf{x}_t = [x_{t,1} \ x_{t,2} \ \cdots \ x_{t,N}]^T$, $t=1,2$ is the data symbol (N sub-carriers) at time t . The symbols are transformed to time domain by IFFT and amplified by the HPA and then transmitted by antennas.

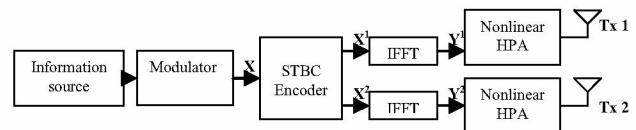


Figure 1 Transmit Block Diagram of STBC-OFDM

The receiver with RFO compensation is shown in Figure 2.

Signals from antennas firstly pass matching filters, and then are sampled and the cyclic prefix is removed from each frame. Then FFT is applied followed by STBC decoder.

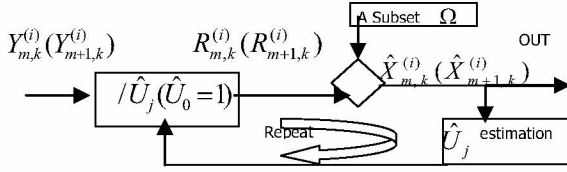


Figure 2 Receiver Block Diagram of STBC-OFDM

In burst mode MIMO-OFDM system, even very small RFO will cause significant degradation of the BER performance especially at the latter part of data symbols in the burst frame [4]. A decision-directed technique for compensation of phase noise and RFO is proposed in [2] which models the system by

$$Y_{m,k}^i \approx U_{m,0} \sum_l X_{m,k}^l H_{m,k}^{l,i} + n_{ICI,k}^i + w_k^i \quad (2)$$

where $Y_{m,k}^i$ is the k -th sub-carrier received signal of symbol m at antenna i , $H_{m,k}^{l,i}$ is the k -th tap of the DFT of the corresponding CIR from Tx antenna l to Rx antenna i , $X_{m,k}^l$ denotes the corresponding transmitted symbols by antenna l , $n_{ICI,k}^i$ is the inter-carrier-interference (ICI), and $U_{m,0}$ term is resulted from the RFO. The $U_{m,0}$ term can be evaluated by

$$U_{m,0} = \frac{\sum_i \sum_{k \in \Omega} Y_{m,k}^i \sum_l (H_{m,k}^{l,i})^* (\hat{X}_{m,k}^l)^*}{\sum_i \sum_{k \in \Omega} \left| \sum_l \hat{X}_{m,k}^l H_{m,k}^{l,i} \right|^2} \quad (3)$$

where $\hat{X}_{m,k}^l$ is the decision observation, Ω is a carrier subset. Then, the RFO is compensated by dividing $Y_{m,k}^i$ by $U_{m,0}$.

However, this scheme does not consider the nonlinearity introduced by HPA, which can be significant if the HPA works in the strong nonlinear region due to the high peak to average power ratio (PAPR). As can be seen by the numerical computation in Section 4, the performance of the RFO compensation technique proposed in [2] will degrade a lot when the nonlinearity exists.

3. THE PROPOSED APPROACH

In order to solve the problem mentioned above, we propose a scheme depicted in Figure 3.

We use decision-based algorithms for both nonlinearity elimination and RFO compensation. Assume that signal at the output of transmitter HPA are:

$$\mathbf{y}_{out}^i = \mathbf{y}^i + D^i \quad (4)$$

where $i=1,2$ and y^i is the symbol input to i th HPA and D^i is the distorted term [5].

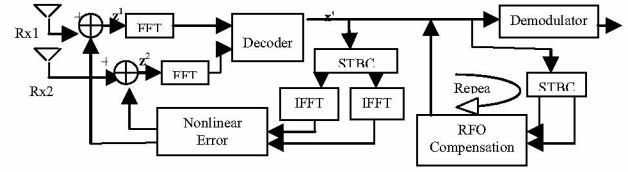


Figure 3 Block diagram of nonlinearity and RFO cancellation

The received signal can be expressed as

$$\mathbf{y}_{rec}^i = \mathbf{y}^i \otimes \mathbf{h}^i + D^i \otimes \mathbf{h}^i \quad (5)$$

where \mathbf{h}^i is the channel response, and " \otimes " is convolution. The main idea of the proposed nonlinearity cancellation scheme is to use a nonlinear system which yields replica of the nonlinear distortion components, that is, the second term in (5), and then use the replica to cancel the nonlinear distortion components in the received symbols. The outputs after this nonlinear distortion are as follows:

$$\mathbf{z}^i = \mathbf{y}_{rec}^i - \hat{D}^i \otimes \mathbf{h}^i \quad (6)$$

where \hat{D}^i is the nonlinear component replica which can be reconstructed by using the same HPA modeling as formula (4) with decision observations

$$\hat{D}^i = (\mathbf{y}_{rec}^i)_{out} - \mathbf{y}_{rec}^i \quad (7)$$

where $(\mathbf{y}_{rec}^i)_{out}$ is the output of HPA modeling when the input is \mathbf{y}_{rec}^i .

After the nonlinearity is removed, the detected signals can be used for RFO compensation. The RFO compensation scheme can be the same as that proposed in [2]. However, since the RFO is approximately proportional to the symbol index m , the decision observations are still degraded severely especially in the latter part of data symbols in a burst. If we use these decision observations to compensate the RFO, the performance will still be not satisfied. Therefore we propose a symbol-by-symbol scheme as follows.

In this scheme, the RFO in a symbol is firstly estimated based on two previous symbols

$$\psi_B^i = \frac{1}{N} \sum_{n=0}^{N-1} \{ \text{Arg} [\hat{y}_{rec,m-1,n}^i \cdot y_{rec,m-1,n}^{i*}] - \text{Arg} [\hat{y}_{rec,m-2,n}^i \cdot y_{rec,m-2,n}^{i*}] \} \quad (8)$$

where $\hat{y}_{rec,m-2}^i$, $\hat{y}_{rec,m-1}^i$ and $y_{rec,m-2}^i$, $y_{rec,m-1}^i$ are the two previous symbol observations after and before RFO compensation respectively, and $\text{arg}[x]$ is the argument of x . Using (8), the phase rotation of symbol m due to the RFO can be compensated by [4]

$$\hat{y}_{rec,m}^i = y_{rec,m}^i \cdot e^{-j(m-\frac{3}{2})\psi_B^i} \quad (9)$$

Then the residual one is further compensated by using the scheme proposed in [2]. Note that the nonlinearity and

RFO compensation processing can be repeated if necessary.

4. NUMERICAL RESULTS

Computer simulations are performed to test the performance of the proposed approach. The parameters used in our simulations are as follows: the system has two transmitting and receiving antennas and has 128 OFDM sub-carriers. The channels are of Rayleigh fading. The high power amplifier at the transmitter RF stage has been modeled as a non-linear circuit with the amplitude characteristic:

$$A_{out} = \frac{A_{in}}{\left(1 + \left(\frac{A_{in}}{A_0}\right)^{2p}\right)^{\frac{1}{2p}}} \quad (10)$$

where A_{in} and A_{out} are the amplitudes at the input and at the output of an amplifier, respectively, A_0 is the maximum (saturation) amplitude at its output, while p is the so-called *Rapp's parameter*. A good approximation of the AM/AM characteristics of existing amplifiers is obtained with the parameter p in the range of 2 to 3 [6]. For large values of p the model converges to an amplifier that is perfectly linear until it reaches its saturation level. For our simulations we have chosen $p=2$. The saturation level is described by the *IBO* (*Input Backoff*) parameter, which is defined as:

$$IBO = 10 \log \frac{A_0^2}{A_{av}^2} \quad (11)$$

where A_{av} is the signal amplitude having the power equal to the average OFDM signal power.

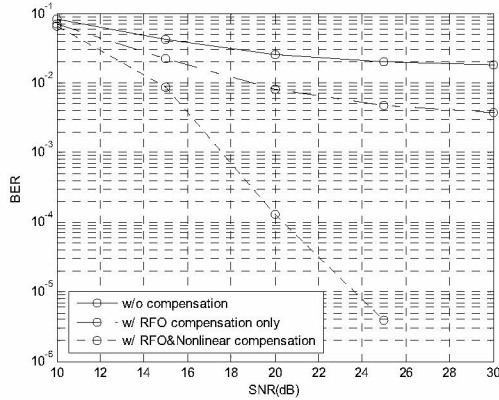


Figure 4 BER performances versus SNR for 16QAM when IBO=2dB

Figure 4 shows the BER performances versus signal noise ratio (SNR) for 16QAM when IBO=2dB with comparison to that of a receiver without any compensation and to a receiver with RFO compensation only. We can see that since the nonlinearity is very strong, so the BER performance without RFO and nonlinearity compensation

is very poor. If we use RFO compensation only, the results is better but still not good. However if we use the nonlinearity compensated detection to compensate the RFO, the results will be improved greatly.

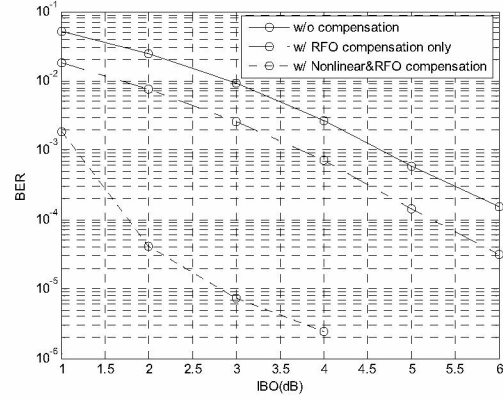


Figure 5 BER performances versus IBO for 16QAM when SNR=20dB

Figure 5 presents the BER performances versus IBO for 16QAM when SNR=20dB. It can be observed that the IBO performance of the compensated signals can be improved about 3.5dB at BER=10⁻⁵.

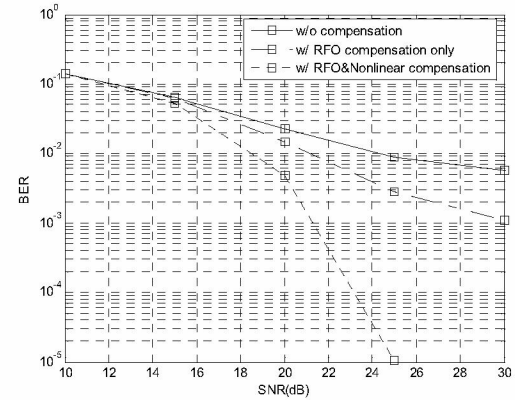


Figure 6 BER performances versus SNR for 64QAM when IBO=4dB

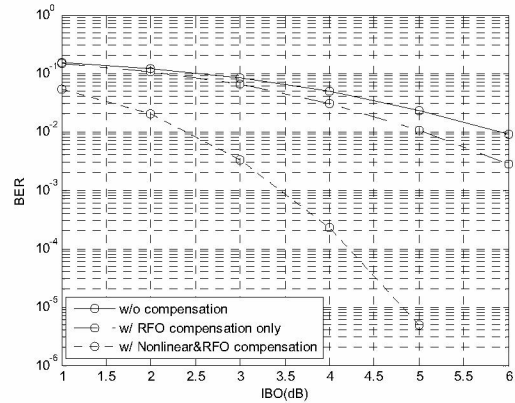


Figure 7 BER performances versus IBO for 64QAM when SNR=25dB

Figure 6 and figure 7 show the BER performance versus SNR when IBO=4dB and BER performances versus IBO

when SNR=25dB, respectively, for 64QAM. From these figures, we can draw almost the same conclusions with 16QAM cases.

5. CONCLUSIONS

In this paper, we propose a RFO compensation scheme in the burst mode MIMO-OFDM systems when severe nonlinearity exists in the HPAs. With the proposed technique, the nonlinearity is eliminated by a decision aided method, and then the RFO is compensated by a modified decision aided approach. It is shown that the BER performance can be significantly improved by proposed technique.

One problem associated with the approach is that the nonlinearity model is assumed to be known which may not be true in practice, and deviation of the model will result in degrade of the performance. In fact more work should be done regarding the modeling of the HPA nonlinearity, which may be an issue for further research.

6. REFERENCES

- [1] D. Gesbert, M. Shafi, and D. Shiu, etc, "From Theory to Practice: An Overview of MIMO Space-Time Coded Wireless Systems," IEEE journal on selected areas in communications, Vol.21, No.3, pp. 281-302, 2003.
- [2] K. Nikitopoulos and A. Polydoros, "Decision-Directed Compensation of Phase Noise and Residual Frequency Offset in a Space-Time OFDM Receiver," IEEE communications letters, Vol.8, No.9, pp. 573-575, 2004.
- [3] C. Bos, M. Kouwenhoven and W. Serdijn, "Effect of Smooth Nonlinear Distortion on OFDM Symbol Error Rate," IEEE transactions on communications, Vol.49, No.9, pp. 1510-1514, 2001.
- [4] H. Kobayashi, "A Novel Coherent Demodulation for M-QAM OFDM Signal Operating in the Burst Mode," IEEE Vehicular Technology Conference (Fall), 2000.
- [5] P. Banelli and S. Cacopardi, "Theoretical analysis and performance of OFDM signals in nonlinear AWGN channels," IEEE Transactions on Communications, vol. 48, no. 3, pp. 430-441, 2000.
- [6] R. van Nee, R. Prasad, "OFDM For Wireless Multimedia Communications", Artech House Pub., Boston, London 2000.